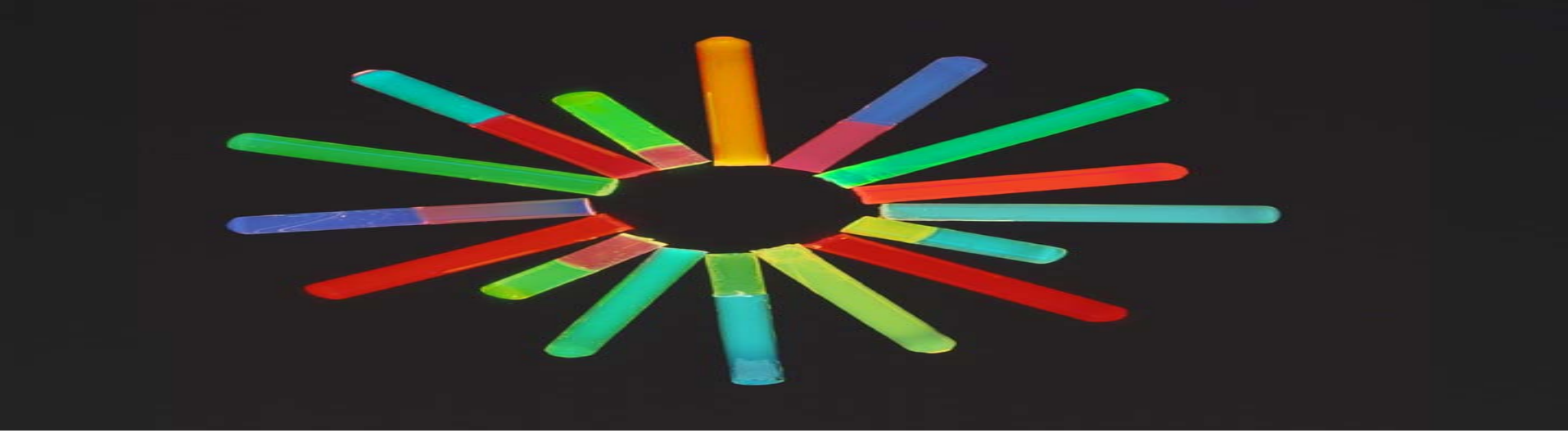


National Nanotechnology Initiative

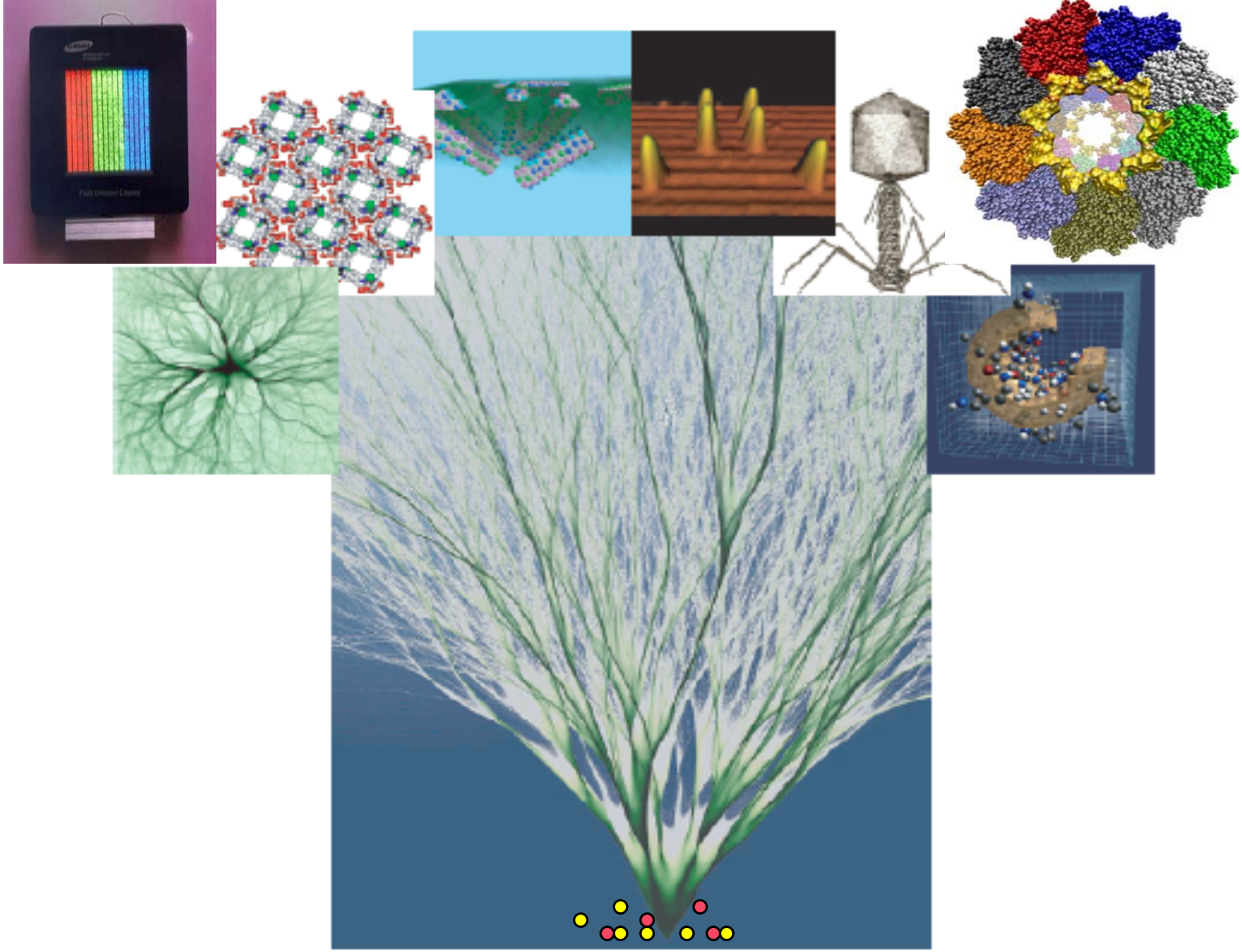
Planning for the Next 5 years

Dr. M.C. Roco

Chair, Subcommittee on Nanoscience, Engineering and Technology (NSET),
National Science and Technology Council (NSTC)

Senior Advisor for Nanotechnology, National Science Foundation

NNI Conference, April 1, 2004

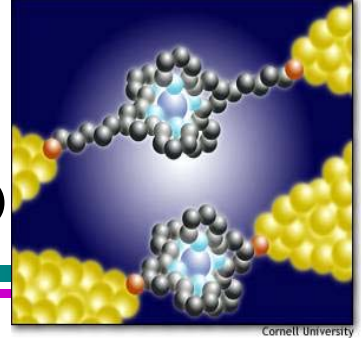


National Nanotechnology Initiative

R&D *Leading to the Next Industrial Revolution*

Nanotechnology

Definition on www.nano.gov/omb_nifty50.htm (2000)



- **Working at the atomic, molecular and supramolecular levels, in the length scale of approximately 1 – 100 nm range, in order to understand, create and use materials, devices and systems with fundamentally new properties and functions because of their small structure**

- **NNI definition encourages new contributions that were not possible before.**

  - novel phenomena, properties and functions at nanoscale, which are nonscalable outside of the nm domain

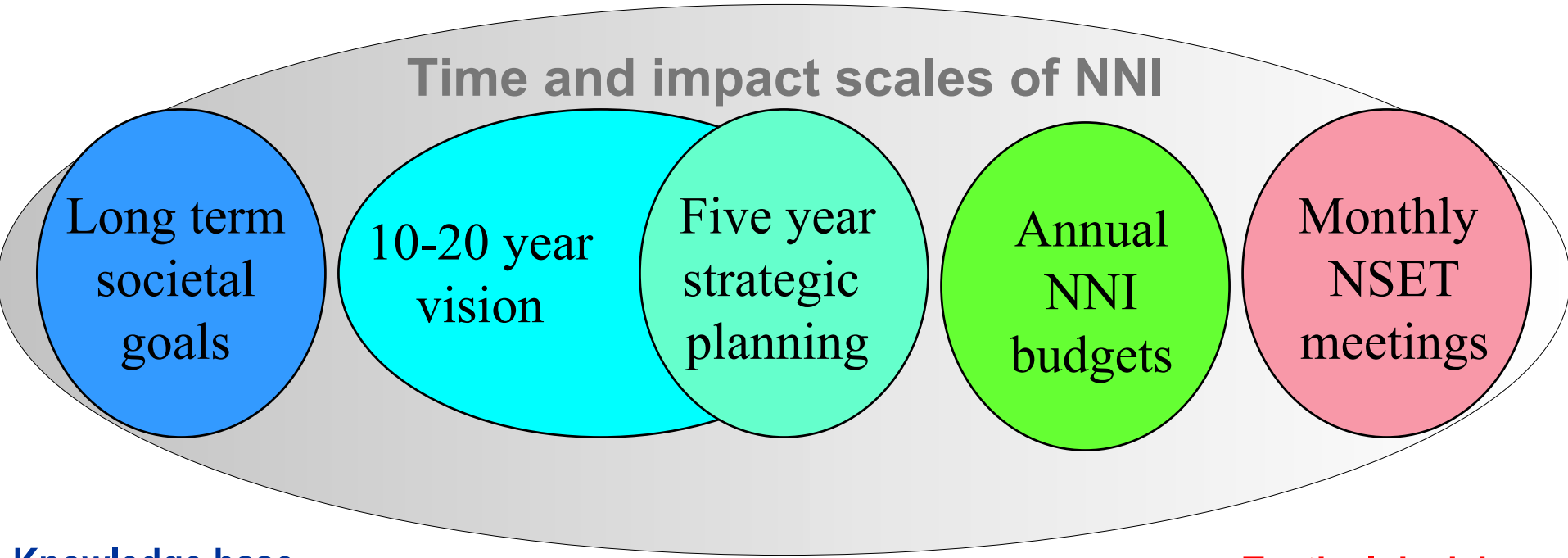
  - the ability to measure / control / manipulate matter at the nanoscale in order to change those properties and functions

  - integration along length scales, and fields of application

Why nanotechnology is important?

- **Reaching at the foundation of matter**
  is a historical event in S&E for understanding and control of natural and man made systems
- **Key driver: The long term societal implications**
  Comprehension of nature, quality of life (health, environment)
  Economy $1T market by 2015, 2 M+ jobs worldwide
- **Higher purpose goals than development of NT**
  1. Accelerate fundamental and unifying science
  2. More basic and relevant education
  3. Higher efficiency processes and novel products
  4. Molecular medicine
  5. Extend the limits of sustainable development
  6. Increased coherence integration of S&T policies toward converging new technologies; unanticipated trends

The long-term vision drives NNI

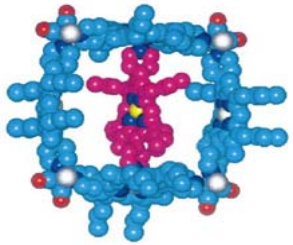


Knowledge base
New technology
Human potential
Responsible NT

1999 Research Directions I
2004 Research Directions II
10 topical reports in 03-04
Evaluation PCAST, NRC

Annual budgets
FY 2001, .. , 2005
OMB crosscut
EOP evaluation

Tactical decisions
Programs
Partnerships
Safety issues



10-20 years vision

Timeline for beginning of industrial prototyping and commercialization

Accidental nanotechnology: since **1000s yr** (carbon black)

Isolated applications (catalysts, composites, others) since **1990**

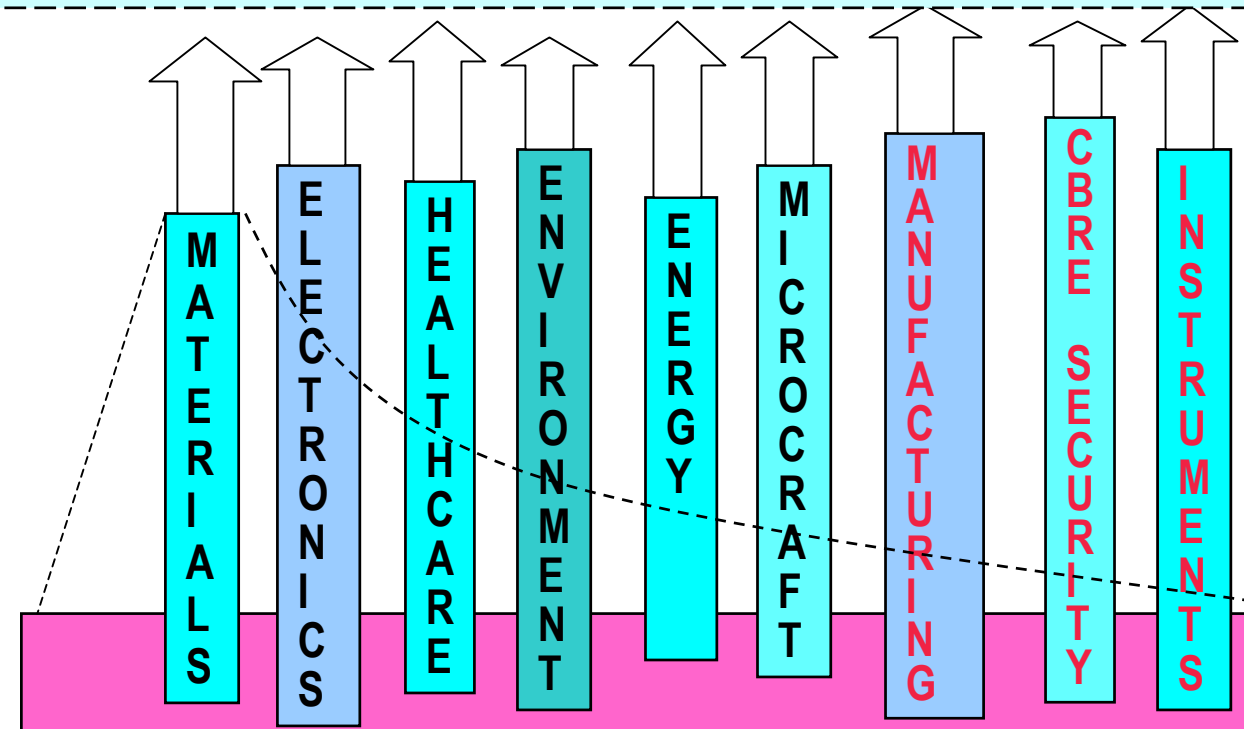
Four generations of nanomanufacturing:

- **First Generation: passive nanostructures**
  in coatings, nanoparticles, bulk materials (nanostructured metals, polymers, ceramics):
  ~ 2001 –
- **Second Generation: active nanostructures**
  such as transistors, amplifiers, targeted drugs and chemicals, actuators, adaptive structures:
  ~ 2005 –
- **Third Generation: 3D nanosystems**
  with heterogeneous nanocomponents; complex networking and new architectures
  ~ 2010 –
- **Fourth Generation: molecular nanosystems**
  with heterogeneous molecules, based on biomimetics and new designs
  ~ 2020 (?) -

(M.C. Roco, AIChE Journal, 2004)

Interdisciplinary "horizontal" **Knowledge Creation** with "vertical" transition from basic concepts to **Grand Challenges** and technology integration - **Converging Technologies**

Revolutionary Technologies and Products



Converging Technologies

Grand Challenges

Fundamental research at the nanoscale

Knowledge Creation: same principles, phenomena, tools

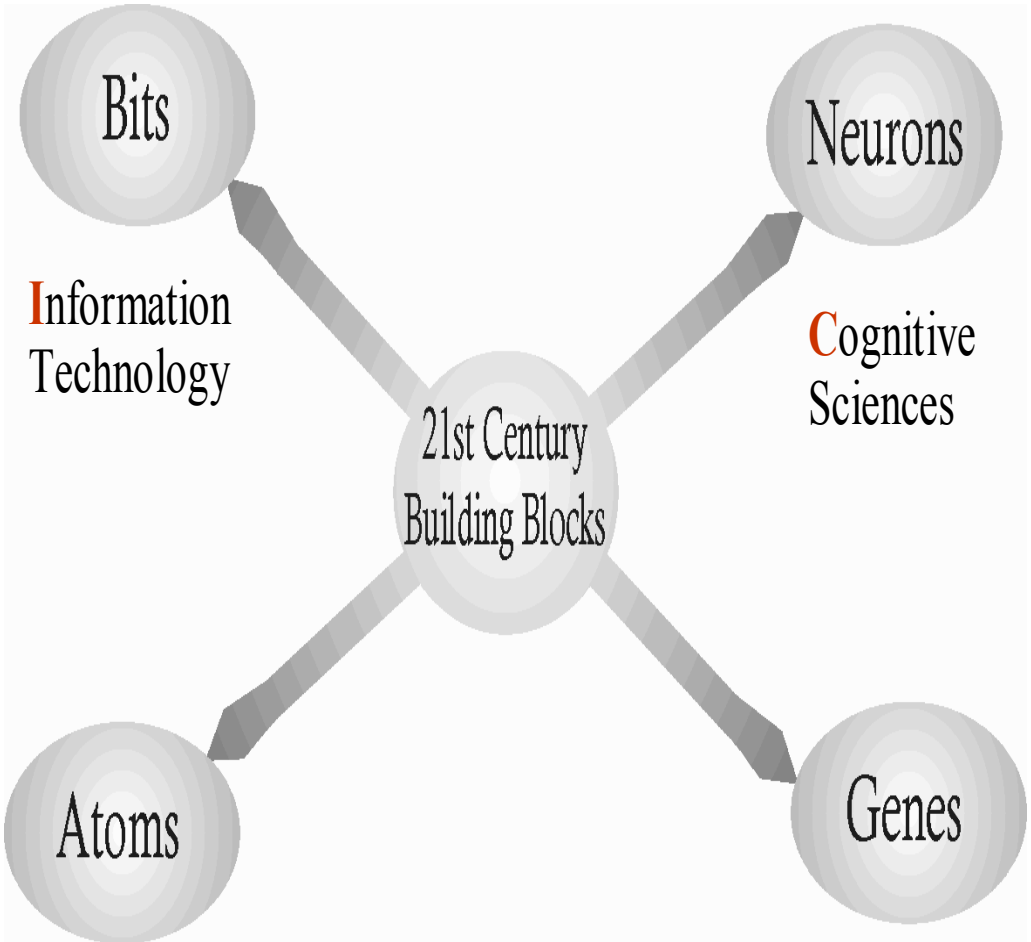
Basic discoveries and new areas of relevance

Infrastructure

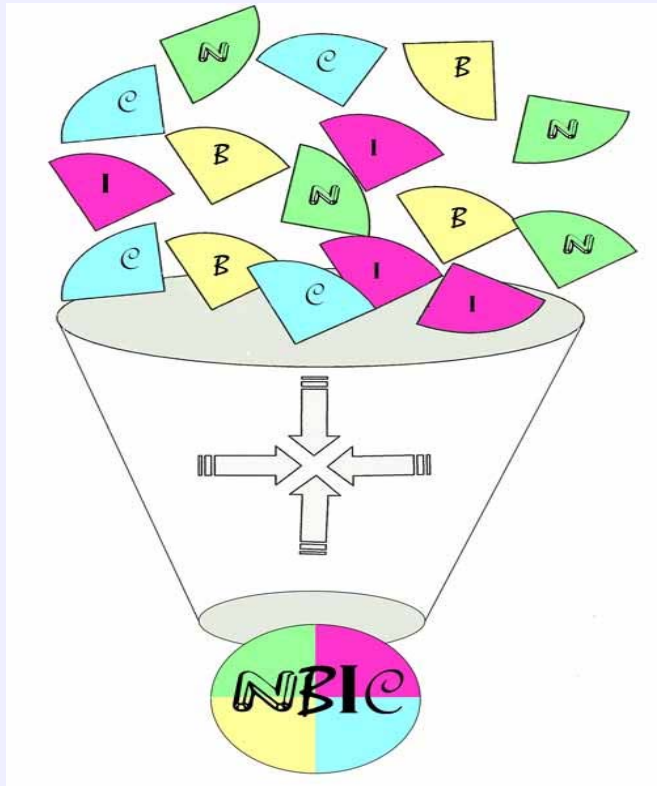
Workforce

Partnerships

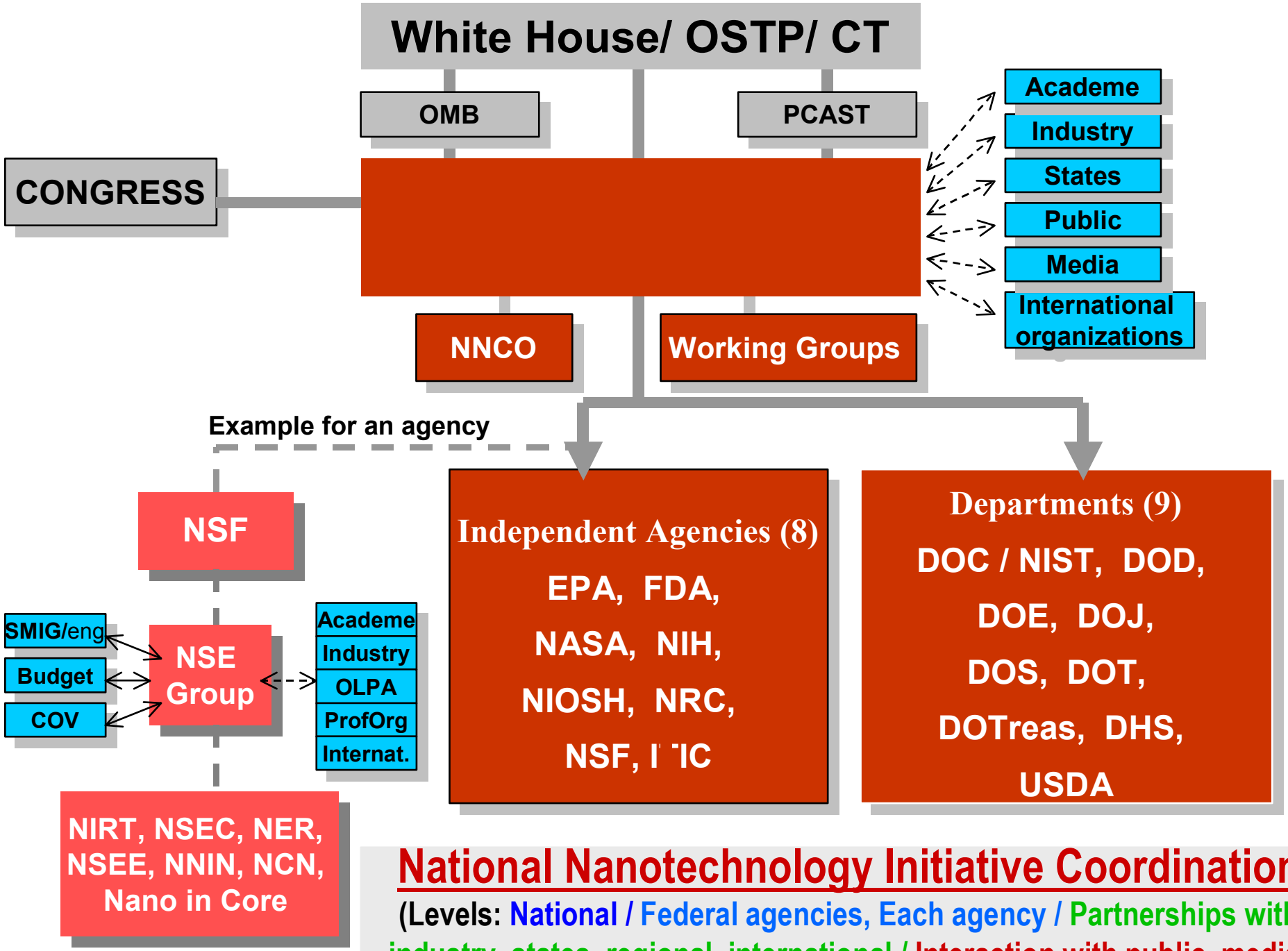
Convergence of new technologies (NBIC)



New: Commercializing and Managing the Converging New Technologies



NSF sponsored workshop (Sept 2003) and NWU report (April 2004)



National Nanotechnology Initiative Coordination

(Levels: National / Federal agencies, Each agency / Partnerships with industry, states, regional, international / Interaction with public, media)

NNI-Industry Consultative Boards for Advancing Nanotech
NNI-SRC, 2003 ; b. NNI-CCR, 2004

Ex: NNI-SRC CBAN for

- Joint planning and support of collaborative activities in key R&D areas
- Identify and promote new R&D for exploratory areas or niche markets
- Periodical joint meetings and joint reports
- Exchange information

Consultative Board (with five working groups)

NNI: M.C Roco (NNI, NSF), C. Lau (NNI, DOD)

SRC: P. Gargini (SRC, Intel); R. Cavin (SRC)

Outcomes since 10/2003: Reciprocal gains

Joint workshop report; Establish five working groups;
NSF-SRC agreement; Three NSF-SRC workshops

NNI: R&D Funding by Agency

Fiscal year (all in million $)	*2000* Actual	*2001* Enact/Actual	*2002* Enact/Actual	*2003* Enact/Actual	2004 Req./ Enact	2005 Req
National Science Foundation	97	150 /150	199 /204	221 /221	249 /254	305
Department of Defense	70	110 /125	180 /224	243 /322	222 /315	276
Department of Energy	58	93 /88	91.1 /89	133 /134	197 /203	211
National Institutes of Health	32	39 /39.6	40.8 /59	65 /78	70 /80	89
NASA	5	20 /22	35 /35	33 /36	31 /37	35
NIST	8	10 /33.4	37.6 /77	66 /64	62 /63	53
EPA	-	/5.8	5 /6	5 /5	5 /5	5
Homeland Security (TSA)	-		2 /2	2 /1	2 /1	1
Department of Agriculture	-	/1.5	1.5 /0	1 /1	10 /1	5
Department of Justice	-	/1.4	1.4 /1	1.4 /1	1.4 /1	1
TOTAL	270	422 /465	600 /697	770 /862	849 /961	982
		+72%	+50%	+24%		

- Industry, state and local organizations: about 1.5 times NNI budget in 2003
- Other NNI (NSET) participants are: OSTP, NSTC, OMB, DOC, DOS, DOT, DOTreas, FDA, NRC, DHS, IC, NIOSH; partnerships with others.

NNI implementation plan published in July 2000

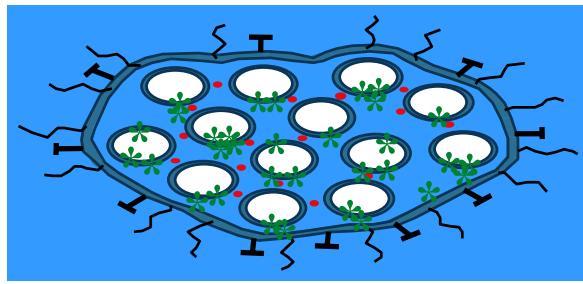
Major changes in the first 3 years of NNI (Part 1)

- **Research**: NNI supports about 2,500 active awards in about 300 academic organizations and 200 private organizations in all 50 states; Developments faster than expected: Reducing the time of reaching commercial prototypes by at least of factor of two for several key applications. Setting new goals.

- **Education**: 7,000 students and teachers trained in 2003; All science and engineering colleges have introduced courses related to NSE. Earlier nanotechnology education.

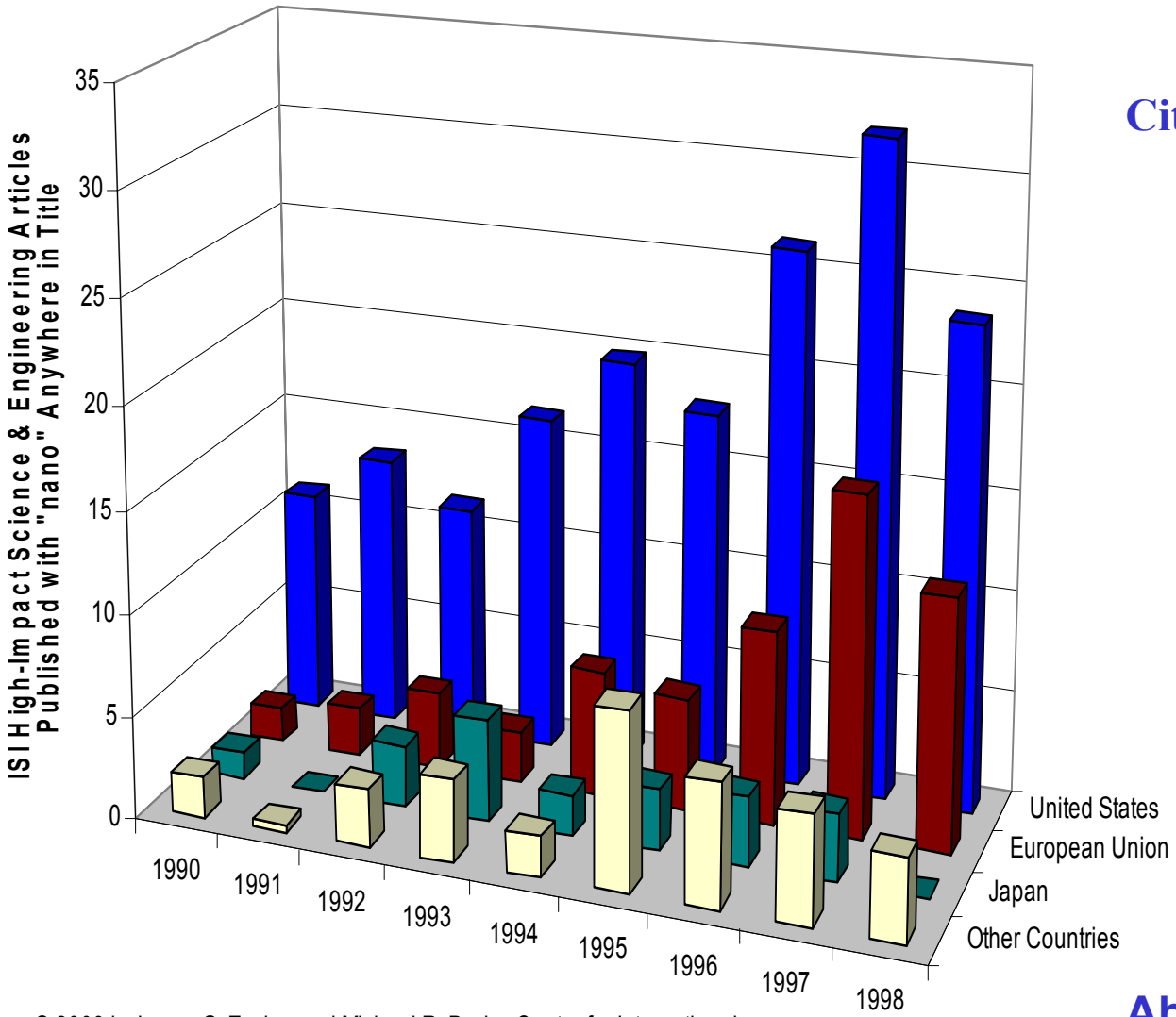
- **Significant infrastructure**: in over 60 universities with user capabilities; Five networks (NCN,NNIN, OKN, DOE, NASA) have been established. About 40,000 workers

Synthesis and control of nanomachines
(examples 2004, www.nseresearch.org - 250 projects)



- **Self-assembly processing** of nanoscale bio-materials and devices for micromachines components (UCSB)
- Chemistry to synthesize components of **nano machines to work on surfaces** and be activated by external electromagnetic fields (UCB)
- **Light driven molecular motors** (U. Nevada)
- **Combinatorial engineering of nanomachines**, with application to membranes and filters (U. Penn.)
- **Nanoengineering surfaces** for probing viral adhesion (UC Davis)

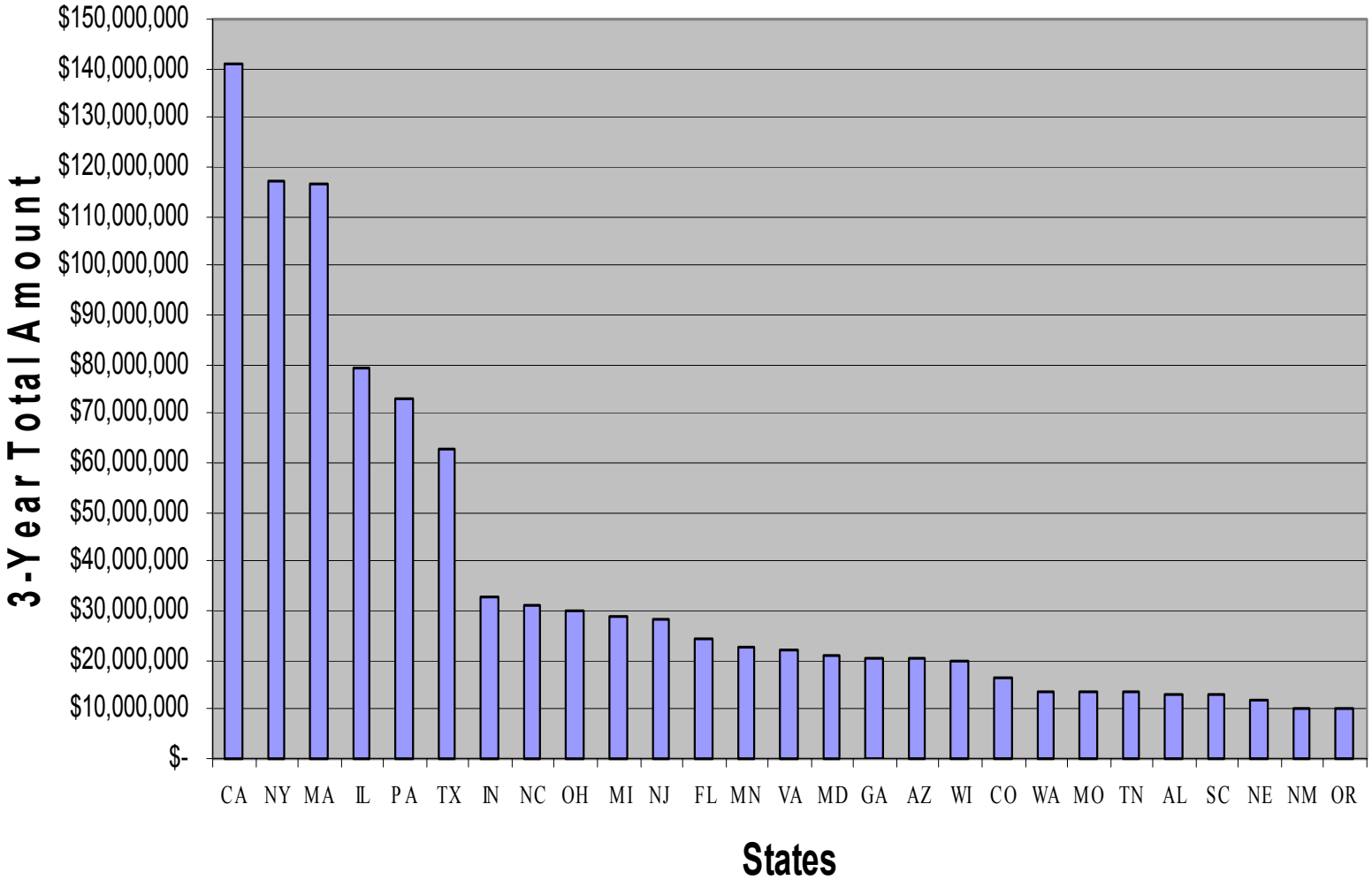
ISI High-Impact Nano-articles, 1990-1998



Citations two years after publication; Data from Institute for Scientific Information, Inc., High Impact Papers, Electronic data base 2000 (using citations for two years after the publ. date; search by nano*)

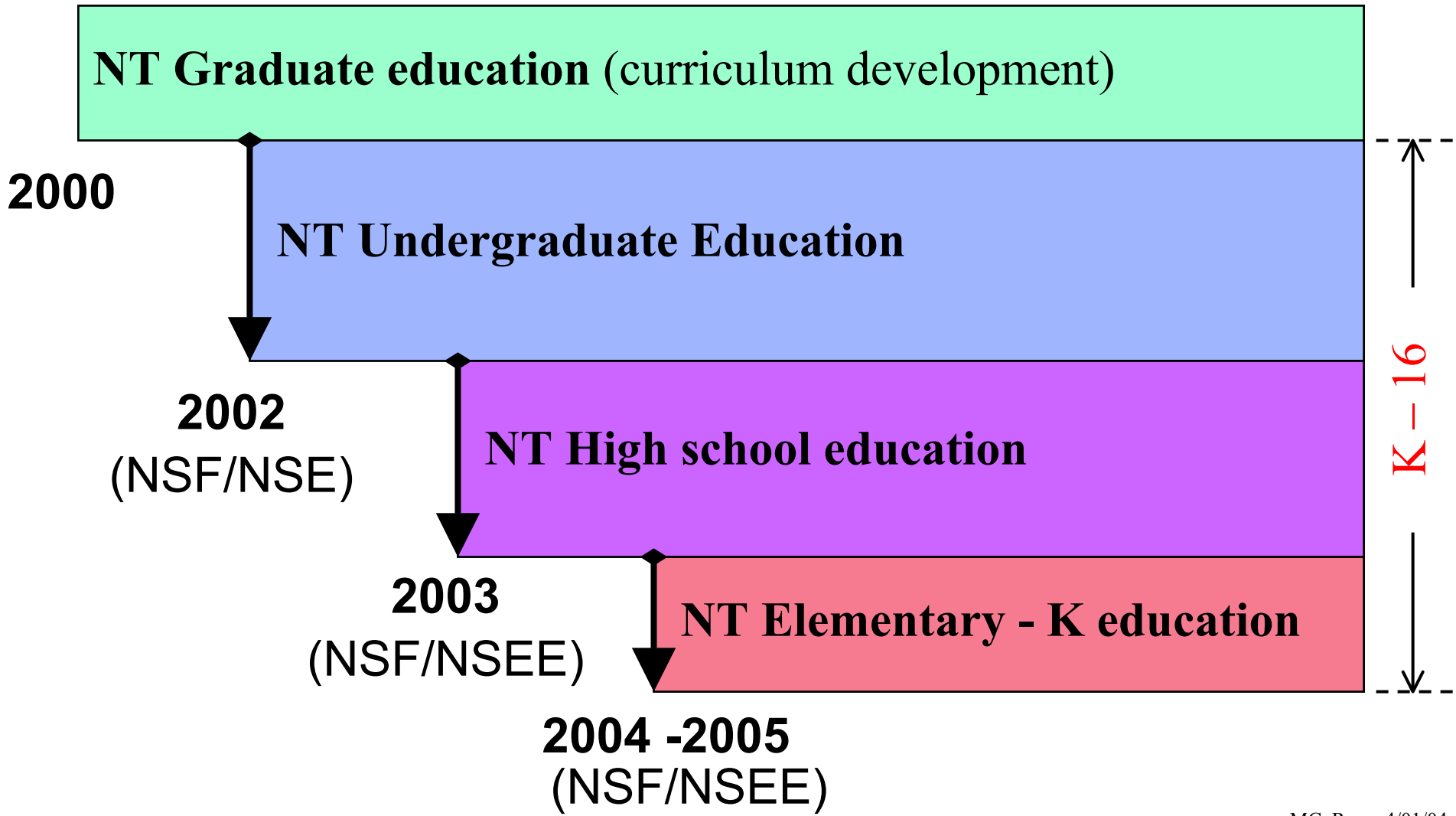
About half of highly cited articles from U.S.

States (US) awarded $10 million or more by NSF for new research grants in FY 2001-2003



M.C. Roco, NSF, 1/27/04

Introducing earlier nanotechnology education
(NSF: Nanoscale Science and Engineering Education)



Objectives for nanotechnology education

- Fundamental understanding from the nanoscale:
  moving the foundation of learning from "microscale" to "nanoscale"
- Sharing similar concepts in various disciplines and relevance areas:
  unifying concepts earlier in education
- **"Reversing the pyramid of learning"**: learning first unifying concepts of matter/ biology/ information systems, and then averaging techniques specific to each discipline
- **Combine "depth" with "breadth"**
- **Broader accessibility and motivation to S&T**
- **Engineering has an increased role** because of its interdisciplinary, integrative, system approach and transforming characteristics. Nanotechnology deals with systems.

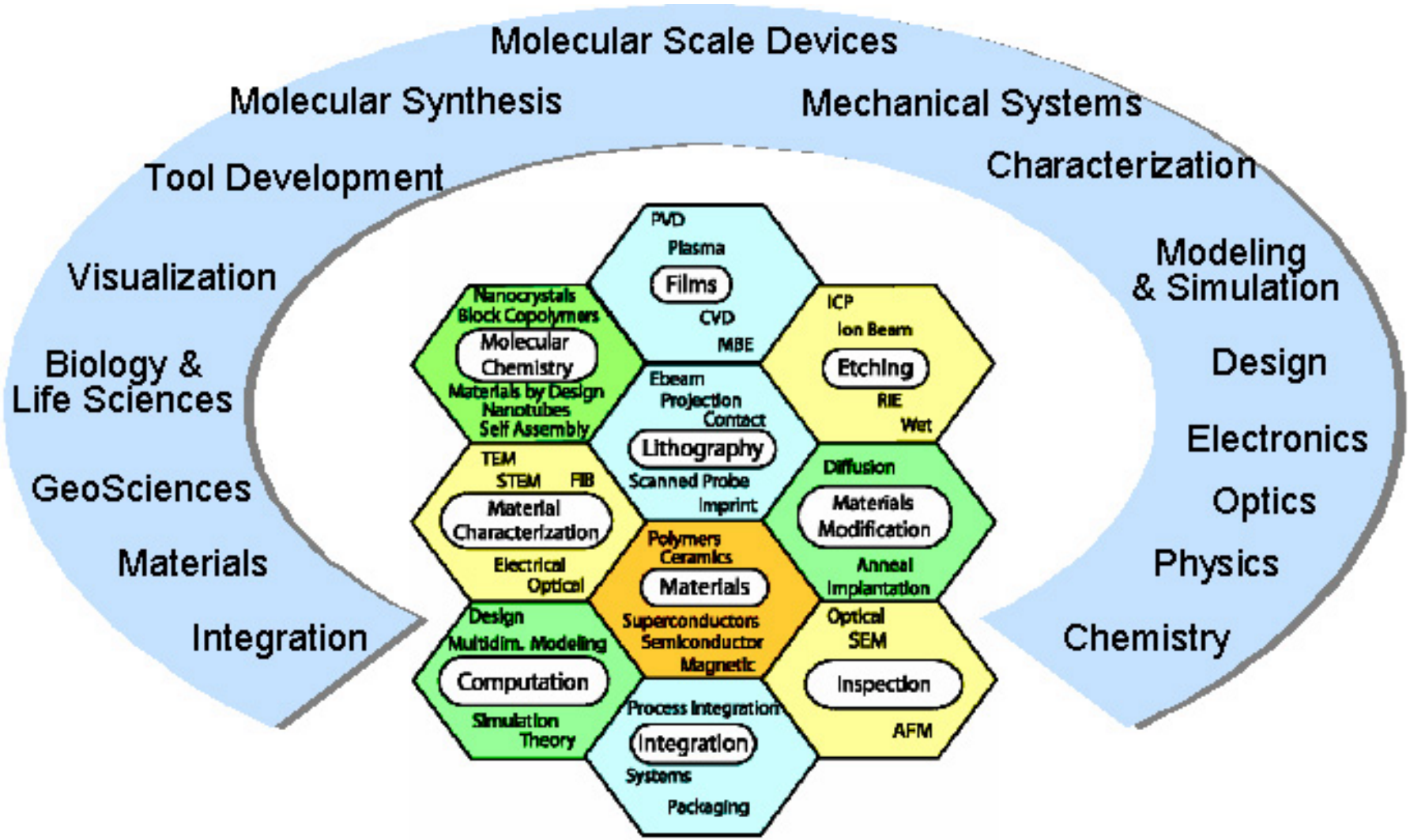
Infrastructure Outcomes of 2001-2003: R&D Networks and User Facilities

- **Network for Computational Nanotechnology** (NCN)
  - **7** universities (Purdue as the central node)
  - Nanoelectronic device simulation/modeling
- **National Nanotechnology Infrastructure Network (NNIN)**
  - 13 universities with user facility
  - Development measuring & manufacturing tools, including NEPM
  - Education and societal implications
- **Oklahoma Nano Net (EPSCoR award)**
- **DOE network for large scale facilities: 5 National Labs**

22 new centers and networks supported by NNI since 2001:

10 NSF, 3 DOD, 5 DOE, 4 NASA (at universities); continuing MRSECs

NSF NNIN Scope and Activities
(13 nodes, lead Purdue University)



DOE Nanoscale Science Research Centers

Summer ‘03

Center For Nanophase Materials Sciences at ORNL

Spring ‘05

Center For Functional Nanomaterials at BNL

Spring ‘04

Molecular Foundry at LBNL

Spring ‘04

Center for Nanoscale Materials at Argonne

Spring ‘04

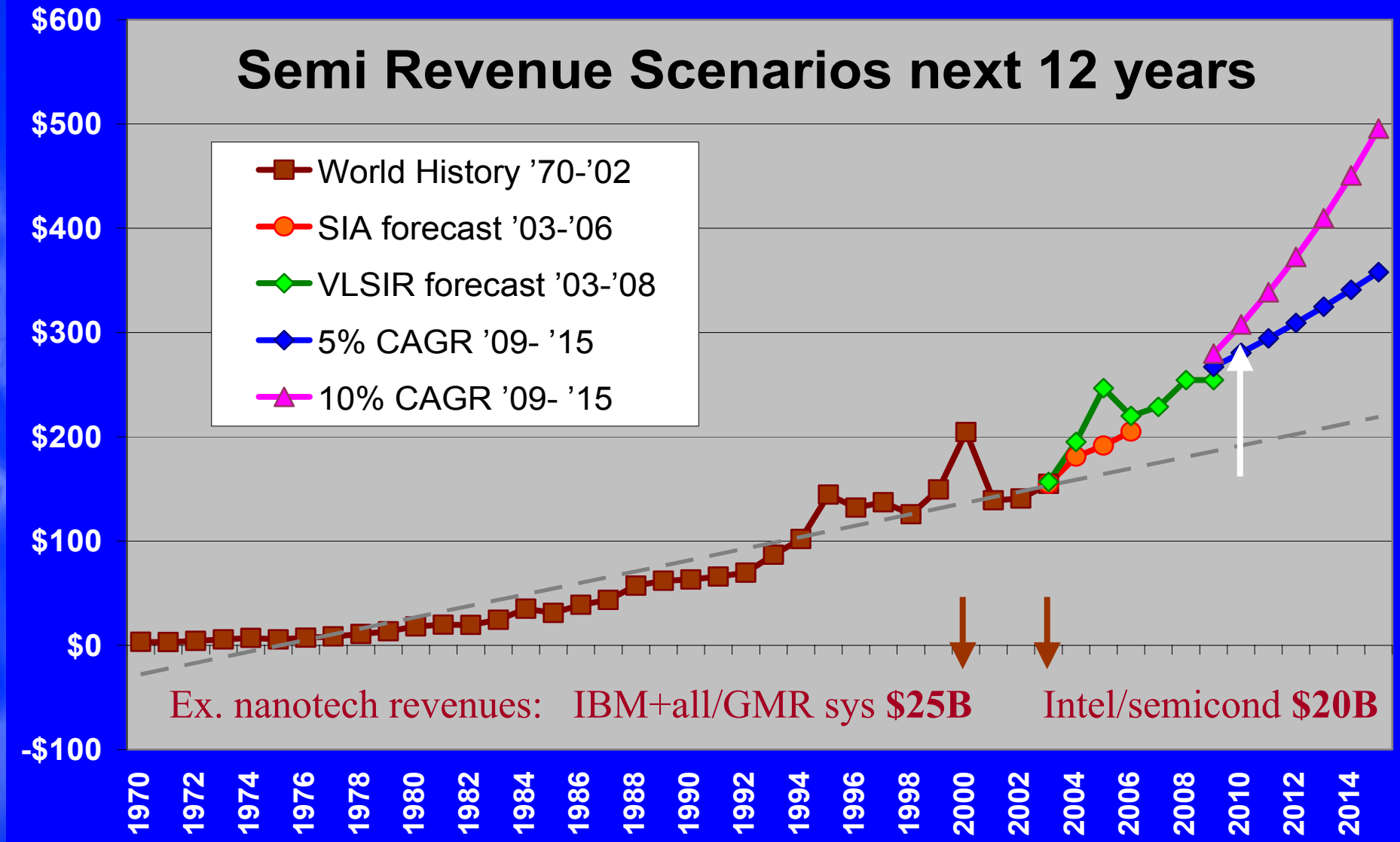
Center for Integrated Nanotechnologies

NNI implementation plan published in July 2000

Major changes in the first 3 years of NNI (Part 2)

- **Industry:** about the same level of investment as NNI in medium and long-term research; Investment by large companies; From "if?" to "how?" and "who will lead?" All 'Fortune 500' in manufacturing and >1000 startups.
- **Innovation and venture funding:** US has over 5,300 patents in 2003 with USPTO (2/3 world)
- **Estimation on revenues from nanotechnology:** Reaching $1trillion in 2015 worldwide, and the estimations moving closer because of accelerated development; growth >25% per year (catalysts, pharmaceutics, IT, ..)
- **States and regional alliances:** "meltdown" in 2002 - > 20 states committed funding, > 22 regional alliances

Semiconductors Extrapolated to 2015 ($B)



Source: Semiconductor Industry Assn. 70-02; VLSI Research 03-08

Note: $300B nanotech revenues sooner than predicted (2010 instead of 2015)

GE Nanotechnology

Aircraft Engines

Water

Platform Technologies

NanoTubes and NanoRods

NanoParticles

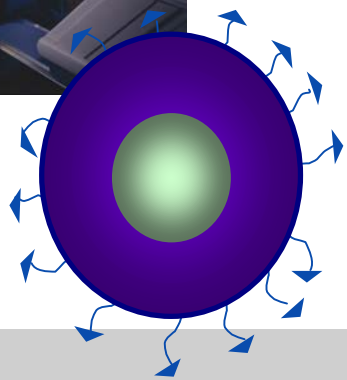
NanoCeramics

NanoStructured Metal Systems

Hybrid Materials

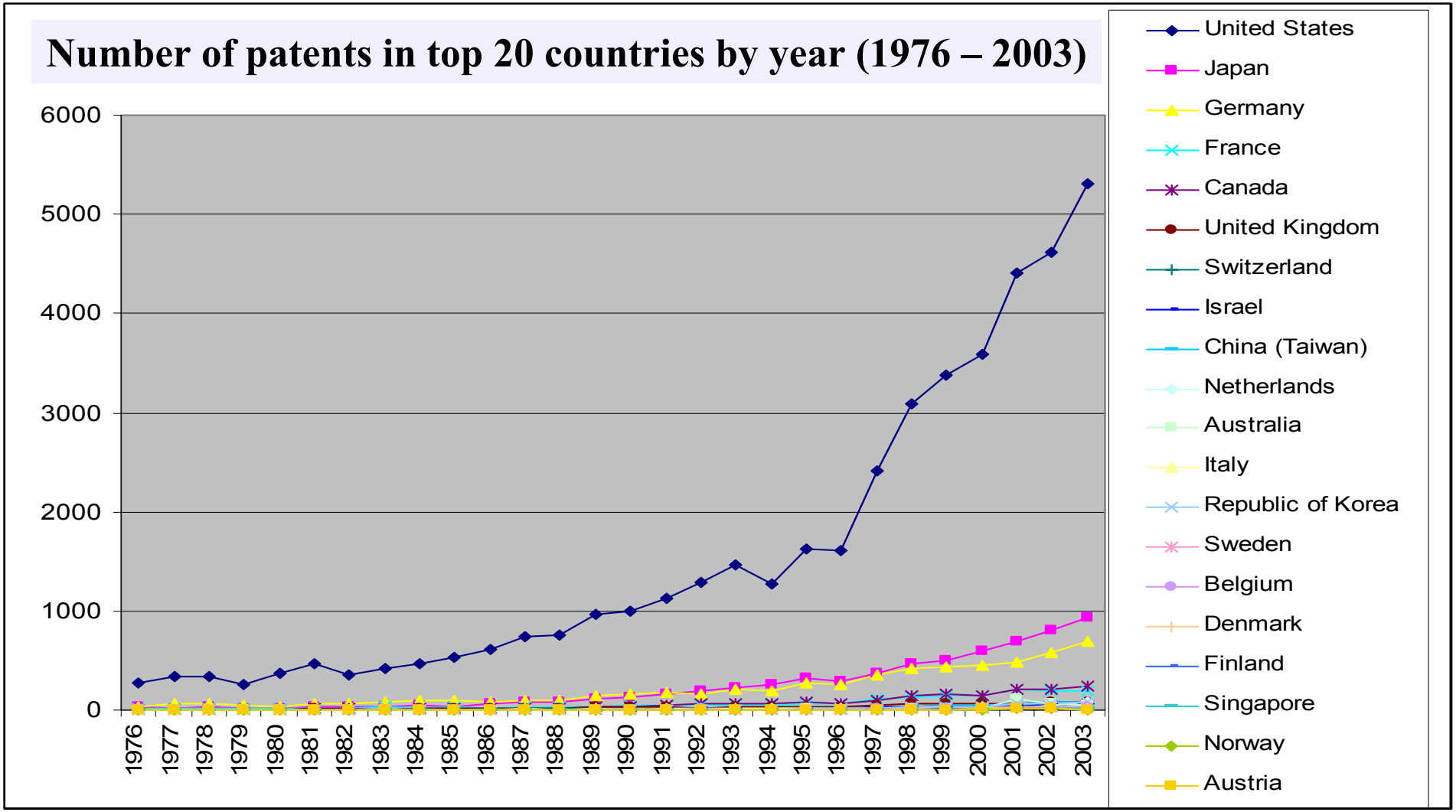
Energy

Healthcare



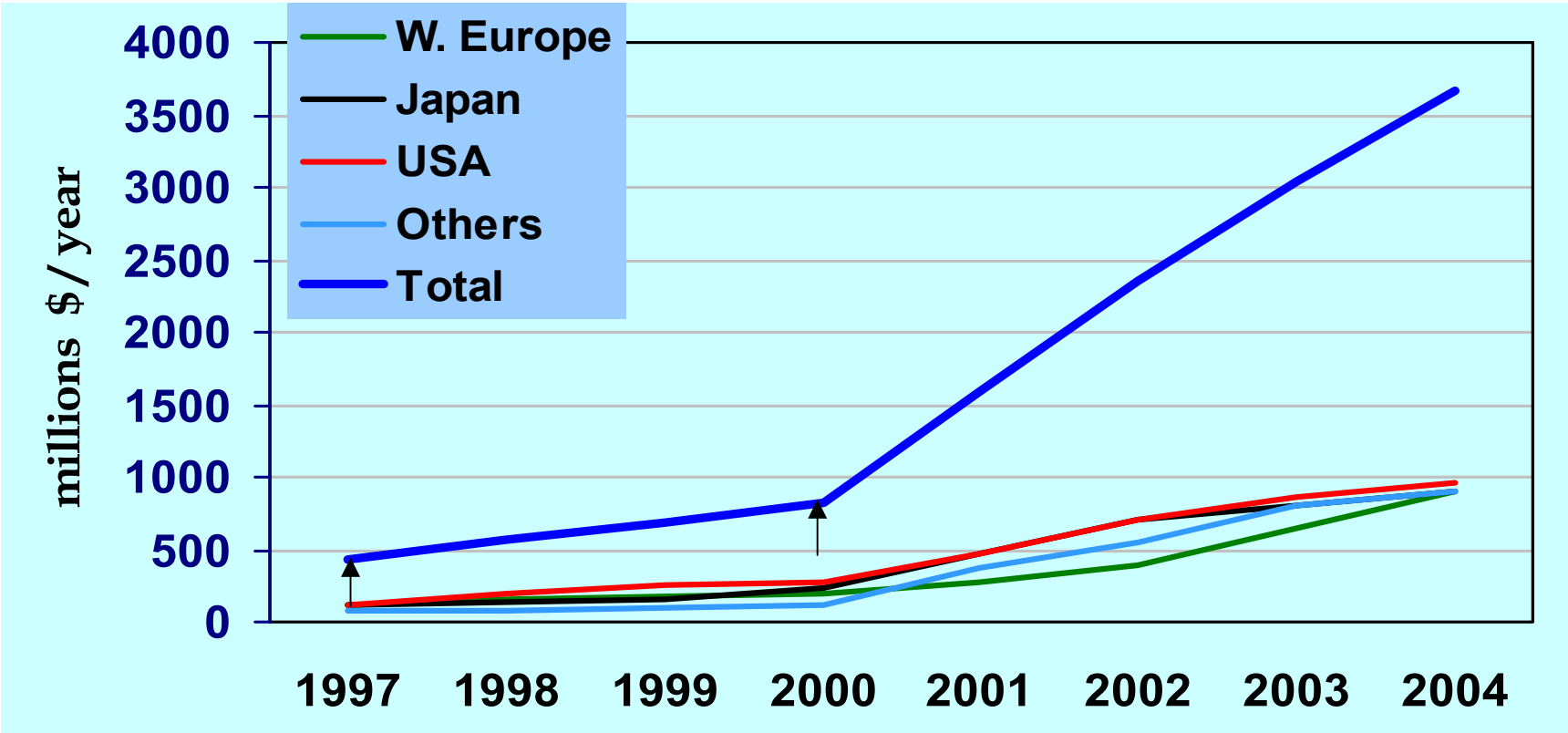
Nanotechnology patents (NSF and ASU, March 2004)

Searched by keywords at USPTO : nano*, atomic force microscop*, atomistic/molecular simulation, biomotor, molecular device, molecular electronics, molecular modeling, molecular motor, molecular sensor, quantum computing, quantum dot*, quantum effect*, scanning tunneling microscop*, selfassembl*



Context – Nanotechnology in the World

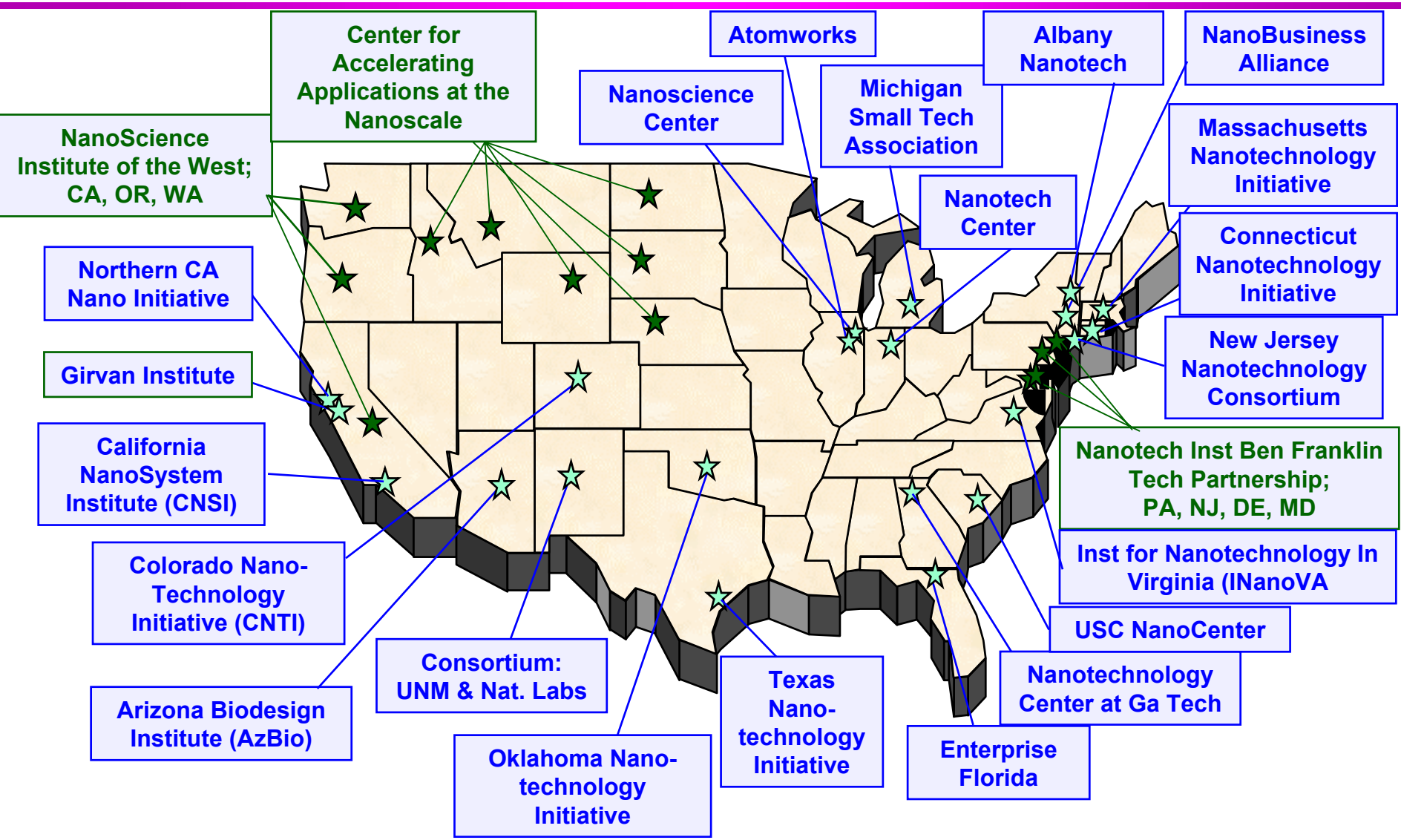
Past government investments 1997-2004 (est. NSF)



Note:

- U.S. begins FY in October, six months in advance of EU & Japan (in March/April)

Sampling of Current Regional, State, & Local Initiatives in Nanotechnology

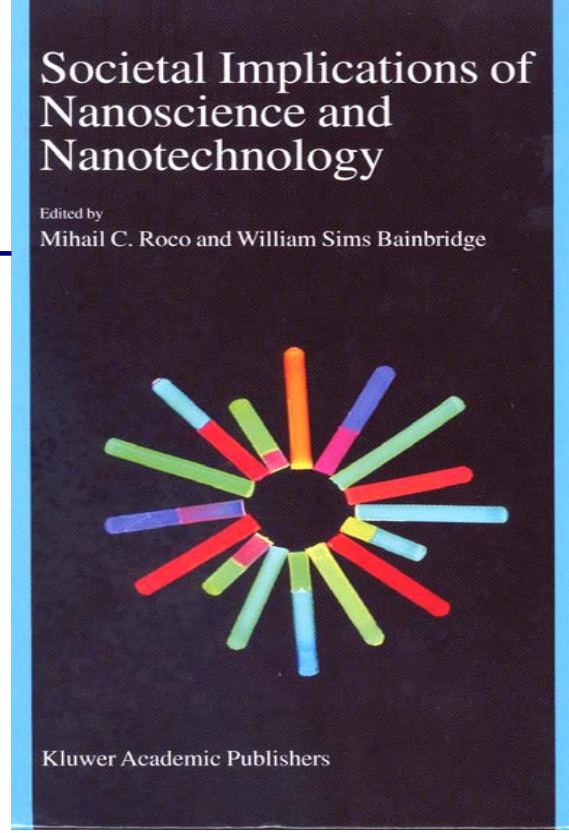


NNI implementation plan published in July 2000

Major changes in the first 3 years of NNI (Part 3)

- **Professional societies**: Specialized divisions, workshops, education; AAAS, ACS, APS, MRS, ASME, AIChE, IEEE, AVS, other major societies in the race
- **Government investment**: Worldwide investment has increased 7 times in 6 years reaching $3B in 2003 (of which US $0.77B and NSF $0.22B)
- **Societal implications from the beginning**: Workshop on Societal Implications of Nanoscience and Nanotechnology in 2000; NSF programs on SI since 2000
- **Other broader implications**: In Federal Government (NNI), Legislative (5 year Bill), Judiciary branches, cultural

Societal Implications: Follow-up of the September 2000 report



- **Make support for social, ethical, and economic research studies a priority:**
  (a) New theme in the NSF program solicitations;
  (b) Centers with societal implications programs;
  (c) Initiative on the impact of technology, NBIC, HSD
- **NNCO – communicate with the public and address EHS, unexpected consequences** http://nano.gov
- **Basic reference for the interaction with the public**
- **Taking faster advantage of the benefits**
- **Converging technologies from the nanoscale**
- **International workshop with EC (2001); Links to Europe and Asia**

Responsible Nanotechnology R&D:

Nanotech EHS Questions and R/D Needs

- Toxicology of new chemicals and materials considered for use in microelectronics and nanotechnology areas
- Interaction of nano-particles with biological systems
- Validation of the current standard methods for EHS assessment of materials
- Development of new methods for rapid and reliable assessment of the EHS impact of process chemicals and product materials.

Nanotech EHS Evaluation

For: Raw materials/ Manufacturing & tools (metrology)/ New process byproducts / Product contents

For: Particles, surfaces

Overview Efforts of NNI on Environment, Health and Safety

(see presentation by Clayton Teague)

- NSF research grants on environmental and societal implications
- NIH research on effects of nanoscale materials in the body
- EPA research grants on environmental implications of manufactured nanomaterials
- National Toxicology Program NTP (NIEHS, NCTR, NIOSH)

  Nanotechnology Safety Initiative, 2003 -
- NIST development of standards and measurements for nanoscale particles
- FDA training
- USDA and

Converging Technologies Bar Association (CTBA)

- Dialog with legal community, public awareness
- Education and reference material for the legal system
- Source of information on implications of converging technologies from the nanoscale
- Advocate policies, regulations and legislation. Anticipatory measures for the implications of NBIC

Harrington v. State

CBTA contacts:

www.convergingtechnologies.org

info@convergingtechnologies.org

NNI implementation plan published in July 2000

Major changes in the first 3 years of NNI (Part 4)

- **Congressional bill and WH Act on nanotechnology (NNI/NNP, 2004-2008)**

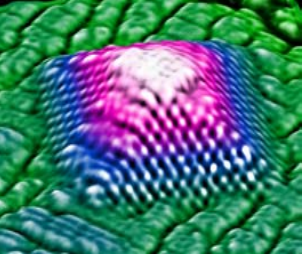
  Bill passed in the House: **H.R.766: "Nanotechnology R&D Act of 2003"**
  Add: nanotechnology fellowships, societal implications

  Bill passed by the Senate's Committee on CSS:

  189 "**21st Century Nanotechnology R&D Act**"
  5-year "National Nanotechnology Program"
  Add: centers on R&D, education and manufacturing

  Congress signed the Bill in November 2003, and
  White House signed the Act on December 3, 2003

- **Create a 'grand coalition' as discussed in Nanotechnology Research Directions in 1999; Create a nanotechnology community**



Planning for the future: expanding the frontiers of nanotechnology

www.nano.gov and www.nsf.gov/nano

Workshops for R&D opportunities (Trends/challenges; Public Reports)

- Nanostructured materials "by design" - Workshops on 10/02, 06/03
- Catalysts that function at the nanoscale - 06/03
- Nanoelectronics, optoelectronics and magnetics - 11/02, 2/03
- CBRE protection and detection - 05/02
- Advanced healthcare, therapeutics, diagnostics - 06/00
- Nano-biology and medicine - 10/03
- Environmental improvement - 06/02, 08/02, 07/03, 09/03
- Efficient energy conversion and storage - 10/02, 02/03
- Microcraft space exploration and industrialization - Spring 04
- Manufacturing processes - 01/02, 05/02; Instrumentation – 01/04
- Agriculture and food systems - 11/02; Converging Technologies – 09/03
- Societal implications (II) - 12/03; Education (NSEE) – 09/03

"Nanotechnology Research Directions (II)" - Fall 2004

After 3 years of NNI:
New R&D potential targets for 2015 (ex.)

2004 **2015**

Nanoscale visualization and simulation of 3D/m domains

Micro domains with nano space and time resolutions

Transistor beyond/integrated CMOS under 10 nm

New catalysts for chemical manufacturing

No suffering and death from cancer when treated

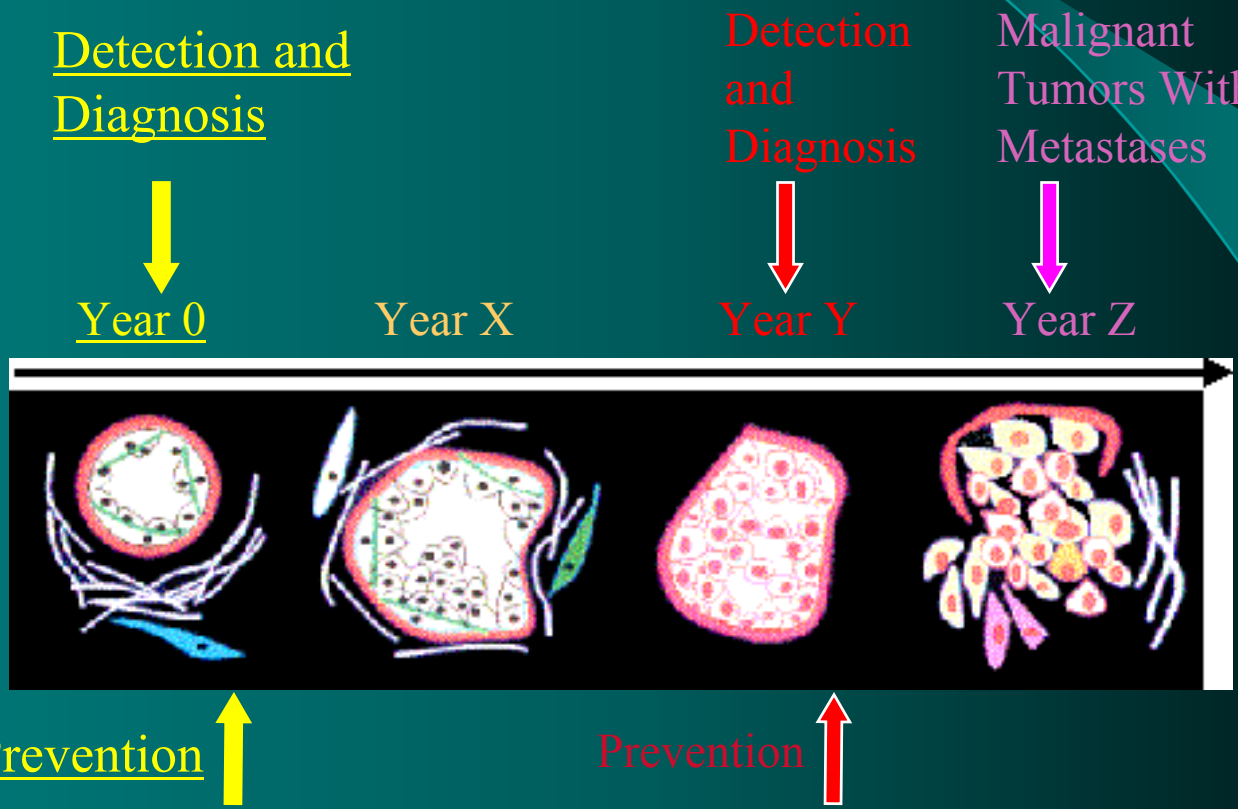
Control of nanoparticles in air, soils and waters

MC. Roco, 4/01/04

Challenge: To Eliminate Suffering and Death Due to Cancer – 2015

"A Vision Not a Dream!" by using nanotechnology, A v. *Eschenbach, NCI*

Where We Want To Be ← Where We Are



Cancer results from accumulation of multiple genetic changes in a cells.

Nanotechnology will allow earlier detection and prevention (Year 0)

After 3 years of NNI:

New R&D potential targets for 2015 (2)

2004 2015

Advanced materials and manu.: ½ from molecular level

Pharmaceuticals synthesis and delivery: ½ based on nano

Converging technologies from the nanoscale

Including: artificial organs, expand life expectancy, increase productivity

Life-cycle biocompatible/sustainable development

Education: nanoscale instead of microscale-based

NNI:
Changing R&D and education focus in 2004

- **Growing area, from discovery to technological innovation**
  - **Materials, including bulk, coating, dispersed systems**
  - **Chemicals, including catalysts**
  - **Pharmaceuticals**
  - **Electronics**
- **Emerging areas in 2003 (support in FY 2004)**
  - **Nanomedicine**
  - **Energy conversion and storage**
  - **Agriculture and food systems**
  - **Molecular architectures**
  - **Realistic multiphenomena/multiscale simulations**
  - **Environmental implications**
  - **Converging technologies from the nanoscale**

Nanotechnology education: What to do in the future?

- **Developing coherent, longitudinal program** with proper bridges between K-12, UG, G, postdoctoral, and continuing education, and encouraging earlier nanotechnology education
- **Targeting systemic changes K-16**
- **Priority to unifying S&E and broad relevance courses**
- **Partnering** for cross-disciplinarity, cross-relevance, and sharing resources (such as facilities and expertise, remote)
- **Enabling the teachers**
  - Training activities periodical available (ex: RET, at centers)
  - Create educational materials (modules, hand-on-kits, course notes)
  - Access to experimental facilities and specialized museums
- **International education opportunities** Young researchers to Japan and EU; PASI - Latin America, NSF-E.C.

NNI challenges

- **Need for coherent, exploratory, long-term (5-10 yrs) plans**
- **Horizontal versus vertical S&T development:**
  0.3% (in 2000) - 0.8% (in 2004) on basics, versus
  5% (basics + precompetitive R&D) of US R&D budget
- **Competitiveness: Strengthening partnership w/ industry**

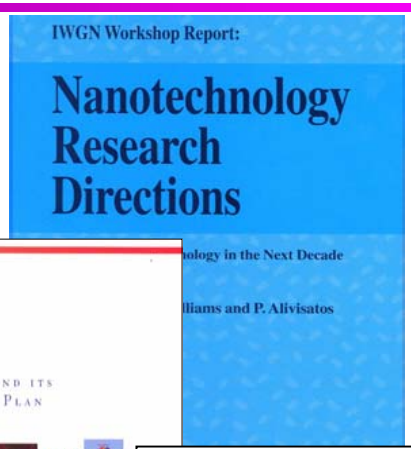
  Need for system-oriented programs, focused on topics such as: the new transistor <10nm, new display, new catalyst, conditioning the cell, S&T convergence

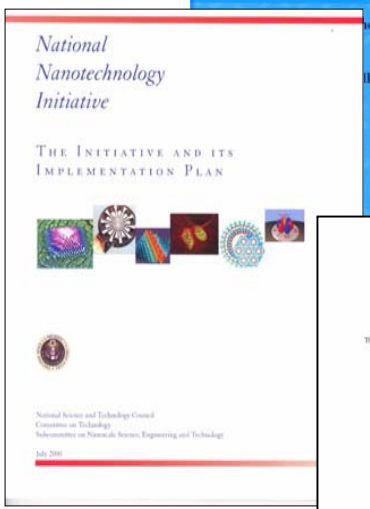
  Support: Joint R&D in university-industry networks and industry-government laboratories to facilitate new technologies and commercialization

APPENDIX

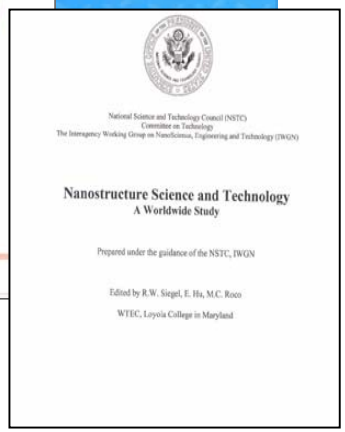
Appendix (1):
NNI Publications after 1999 (www.nano.gov)

1999:
10-year
vision



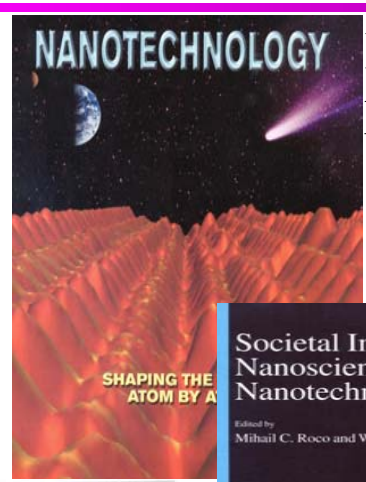


Government
plan



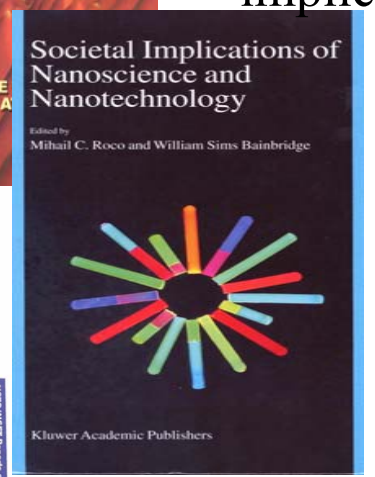
Worldwide
benchmark

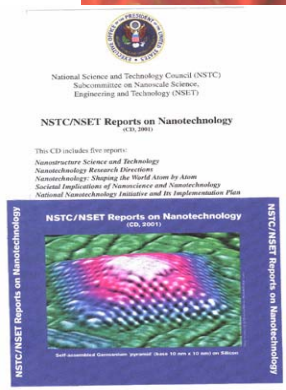
Reports



Brochure for
public

Societal
implications





NSET: "FY 2004 NNI and Its Implementation Plan"

Appendix (2): Reports from NNI Conferences/workshops

Regional workshops of NNI

"Nanotechnology: Opportunities and Challenges"
South-west region; host UCLS, September 2001, wtec.org/nanoreports/FinalUCLAnanoRpt0302.pdf

"From the Laboratory to New Commercial Frontiers"
South-east regional; host Rice University, May 2002, wtec.org/nanoreports/ACF64.pdf

Grand Challenge (topical) workshops

"Nanotechnology Innovation for Chemical, Biological, Radiological, and Explosive Detection and Protection"
May 2002, www.wtec.org/nanoreports/cbre/

"Chemical Industry R&D Roadmap for Nanomaterials By Design: From Fundamentals to Function"
October 2002 Vision 2020/NNI Grand Challenge Workshop, www.chemicalvision2020.org/nanomaterialsroadmap.html

Buildings for Advanced Technology Workshop, at NIST, Jan 14-16, 2003; www.nanobuildings.com/bat/overview/default.htm

Appendix (3):
Other Grand Challenge (topical) workshops

NNI Grand Challenge (GC) Workshop on Nanomaterials, at NSF, June 11-13, 2003

NNI GC Workshop: Nanoscale Processes for Environmental Improvement, at NSF, May 8-10, 2003.

Interagency Grantees Meeting on Nanotechnology and the Environment: Applications and Implications, at NSF, September 15-16, 2003. es.epa.gov/ncer/publications/nano/index.html

NNI Workshop on NanoBiotechnology, Arlington, VA, Oct. 9-11, 2003

NNI Workshop on Societal Implications of Nanoscience and Nanotechnology, at NSF, Dec. 3-5, 2003

NNI GC Workshop on Instrumentation and Metrology for Nanotechnology, at NIST, Jan. 27-29, 2004

NNI GC Workshop on Nano-electronics, -photonics, and -magnetics, Arlington, VA, Feb. 11-13, 2004

NNI GC Workshop on Nanoscience Research for Energy Needs, Alexandria, VA, March 16-18, 2004

Appendix (4): Other Reports on Nanotechnology Sponsored by NNI Agencies, 2000 to Present

Nanoscience and Nanotechnology: Shaping Biomedical Research, Bioengineering Consortium, BECON, report from the June 2000 BECON workshop. www.becon.nih.gov/nanotechsympreport.pdf

***NNI: The Initiative and its Implementation Plan*.** National Science and Technology Council (NSTC), Committee on Technology, Interagency Working Group on Nanoscience, Engineering and Technology (IWGN), July 2000. www.nsf.gov/home/crssprgm/nano/nni2.pdf

Societal Implications of Nanoscience and Nanotechnology. NSF Report, March 2001. www.wtec.org/loyola/nano/societalimpact/; also available in hardcover from Kluwer Academic Publishers, 2001

***WTEC Panel Report on Tissue Engineering,* WTEC, Inc., January 2002. Sponsored by NSF, NIH, DARPA, NIST, and FDA; www.wtec.org/loyola/te/final/; also Academic Press**

***Theory and Modeling in Nanoscience*.** Report of the May 10–11, 2002, Workshop BES/DOE www.sc.doe.gov/bes/Theory_and_Modeling_in_Nanoscience.pdf

Appendix (5): Other Reports on Nanotechnology Sponsored by NNI Agencies, 2000 to Present

Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science. June 2002, NSF/DOC-sponsored report. www.wtec.org/ConvergingTechnologies/; also Kluwer, 2003

***Report of the Nanogeoscience Workshop*, Berkeley, CA, June 14-16, 2002,** Sponsored by NSF. http://www.nsf.gov/home/crssprgm/nano/geo_workshop.pdf

***Nanotechnology and the Environment: Applications and Implications*. EPA Nanotechnology Grantees Workshop,** August 29, 2002. www.nsf.gov/home/crssprgm/nano/GC_ENV_EPA2002_Proc_03-0204.pdf

***Research Directions and Nanoscale Science Research Centers*, DOE/BES, February 2003, www.sc.doe.gov/bes/NSET_NSRC_brochure_FEB03.pdf**

***Nanoscale Science and Engineering for Agriculture and Food Systems*. Report from the National Planning Workshop, Washington, DC, Nov. 18-19, 2002. www.nseafs.cornell.edu/web.roadmap.pdf**

***Emerging Issues in Nanoparticle Aerosol Science and Technology*, National Science Foundation Report, January 2004. www.nano.gov/html/res/NSFAerosolParteport.pdf**

Appendix 6: Other Reports on Nanotechnology Sponsored by NNI Agencies, 2000 to Present

- ***National Nanotechnology Initiative; R&D Supporting the Next Industrial Revolution:*** *Supplement to the President's FY 2004 Budget*, National Science and Technology Council (NSTC), Committee on Technology, Subcommittee on Nanoscale Science, Engineering, and Technology (NSET), Oct. 2003. **www.nano.gov/html/res/nni04_budget_supplement.pdf**
- ***Small Wonders, Endless Frontiers: Review of the National Nanotechnology Initiative*. NRC, June 2002.**
  www.nano.gov/html/res/smallwonder.html